Low Cost Device to Measure the Thickness of Thin Transparent Films

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Abstract— **There is often a requirement to fabricate thin glass plates for prototyping purposes in a research lab. For example to make a prototype of an optic filter there is a need to fabricate a number of thin glass plates and in most moderately equipped optic research laboratory there is facility to etch these glass plates, but lacks instruments to measure its thickness. Our main purpose is to design a system which is cost friendly and is capable of measuring the thickness with a resolution lesser than 1µm. A combination of Michelson interferometer and an electronic fringe counter makes up this instrument. The interferometer produces the fringes which can be made to shift in relation to the thickness of the film to be measured. The number of fringes shifted is recorded be the counter using which the thickness can be determined (note: the refractive index of the plate should be known)**

Keywords— **Thickness, Measurement, Electronic System, Optic Device, Michelson Interferometer.**

I. INTRODUCTION

The Michelson interferometer uses the principle of interferometry, wherein the interference pattern is produced after the splitting and recombination of the beam of light. When a thin film is shifted by a certain angleitintroduces a change in path difference and results in fringe shifts. These shifts are detected using a light sensor whose output is amplified and smoothened. This processed signal is used to produce pulses which are then counted and used to determine the thickness of the transparent film.
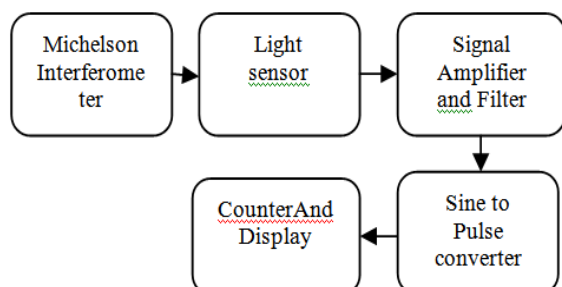
II. MODULES

Figure 1 : Modules

The above figure shows the schematic diagram of the device. The construction and working of each module is described below.

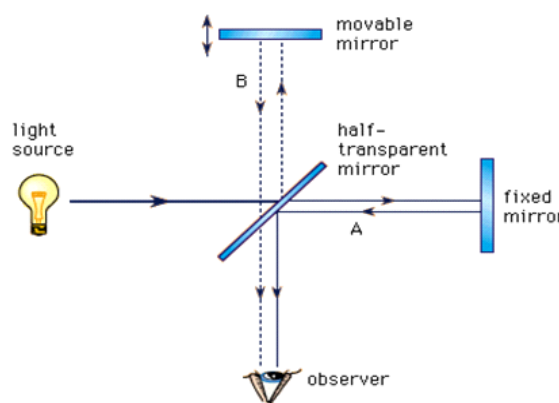### A. Michelson Interferometer

Figure 2 : Michelson Interferometer

The Michelson interferometer, shown in fig 2 is a device that produces interference between two beams of light. Light from a light source is split into two parts. One part of the light travels in a differentpath length compared to the other. After traversing these different path lengths, the t--wo parts of the lightare brought together to interfere with each other. The interference pattern can be seen on a screen. Light from the source strikes the beam splitter. The beam splitterallows 50% of the radiation to be transmitted to the translatable mirror M1. The other 50% ofthe radiation is reflected to the fixed mirror M2. After returning from M1, 50% of the light is reflected towardthe frosted glass screen. Likewise, 50% of the light returning from M2 is transmitted to theglass screen. At the screen, the two beams are superposed and one can observe the interferencebetween them. If two waves simultaneously propagate through the same region of space, theresultant electric field at any point in that region is the vector sum of the electric field of eachwave. This is the principle of superposition. (We assume all waves have the same polarization).

B. Light sensor (stage 1)

Light sensor*fig-3* is an electronic component wherein the resistance changes with respect to the intensity of light. It is used here to detect the fringes. As the resistance changes with the intensity of light the voltage generated will also vary accordingly and this gives rise to an alternating signal.
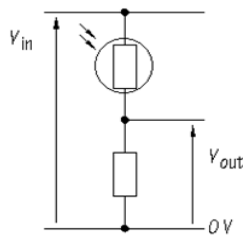
Figure 3: Light Sensor

C. Signal Amplifier and Filter (stage 2 & 3)

The obtained signal is amplified using an instrumentation amplifier, adifferential amplifier which provides good impedance matching and filtered using a second order active low pass filter. Important characteristics include very low DC offset, low drift, low noise, very high open loop gain, very high common mode rejection ratio, and very high input impedances.
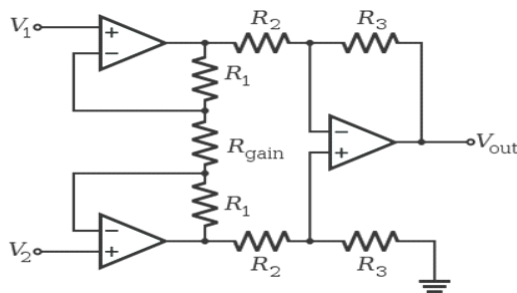

Figure 4 . Signal Amplifier

$$\frac{Vout}{V2 - V1} = \left(1 + \frac{2R1}{Rgain}\right)\frac{R3}{R2} \quad [2]$$

We usethefilterto remove the high frequency noise present in the signal. By using optical equations and geometry the frequency of the sinuous signal from the sensor can be derived mathematically represented as,
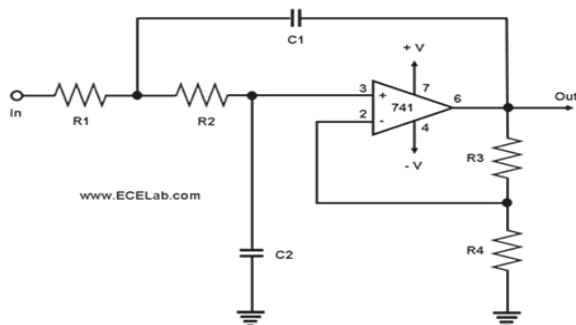

Figure 5 : Filter

$$frequency = \frac{2tk(\mu - 1) \cdot \sec(\varphi) \cdot \tan(\varphi)}{\lambda}$$

t- width of thin film
k- constant in degrees/sec
ì - refractive index thin film
ö- angle through which the glass plate is rotated
ë- wavelength of light

D. Sine to Pulse converter (stage 4)

We use the comparator ICLM324, which consists of four op-amps. By comparing the output of signal from sensor with a reference voltage, a square wave results.
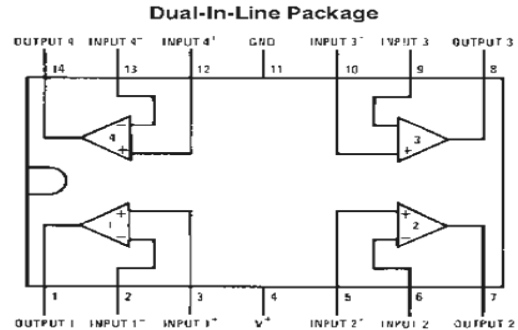

Figure 6 : Sine to Pulse Converter

E. Counter and Display (stage 5)

We use IC 7490 which is a decade counter. It counts the number of pulses arriving at its input.The number of pulses counted (up to 9 in a single counter) appears in binary form.
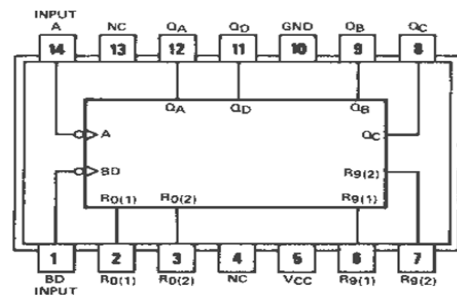

Figure 7 : Counter IC

A seven-segment displayis a form of electronicdisplay device for displaying decimal numerals.IC7447 which is a BCD to &7-segment driver is usedfor interfacing the counter to the 7 segment display unit.

F. Circuit diagram

The complete circuit diagram is presented at the end of the paper (Fig 10).

G. Working

Stage 1: The fringes produced by the Michelson Interferometer are made to fall on the light sensor. The light sensor comprises of a light dependent resistor (LDR) connected with a 940Kohm in series and it is powered by a 9V supply. When there is a transition from light fringe to dark fringe the resistance value of LDR changes from low to high and the output voltage goes from high to low.

Stage 2: This output from the sensor is amplified using an instrumentation amplifier. The approximate sine wave like signal is given to one of the inputs of the instrumentation amplifier and a suitable reference voltage is given to the other input. The reference is chosen such that the output does not saturate for any possible input value. We use 1k ohm and 10 k ohm resistors to provide a gain of 10.

Stage 3: The output of the instrumentation amplifier is then given to a second order active low pass filter. It helps to eliminate the undesirable noise components present in the oscillating signal. The cutoff frequency is set to 1Khz so that noise is eliminated.

Stage 4: The low pass filter output is an amplified sine wave signal, which is given to the comparator IC, LM324. This compares the incoming signal with given reference voltages to produce a 'High' or a 'Low'.This converts the approximate sine waves into pulses. Two comparators are cascaded in series to produce sharp pulses.

Stage 5: We use a decade counter (IC7490) to count the incoming pulses which gives a binary output (BCD). This is given to a BCD to 7-Segement decoder (IC7447) which produces the required 8 digit digital output. This is given to the 7-segment display to show the count in numeric characters. In effect we are counting the number of light fringes that has completely crossed the light sensor when the thin film is rotated. This is then used to determine the unknown thickness of the thin film, using the previously stated formulae.

Note: The refractive index of the thin film should be known.

Though the comparator gives a 'High' for the light fringe and a 'Low' for the dark fringe, only the 'High' to 'Low' transitions are counted by the decade counter hence counting the number of light fringes which completely cross the sensor.

H. Procedure

- Set up the Michelson interferometer unit. Use some standard laser for the light source.
- Place the thin film on a rotating table and place it in the lights path.
- Make sure that the film is perpendicular to the light rays.
- Rotate the thin film through some angle. This results in fringe shifts which are counted by the circuit.
- We now have the refractive index of the film, the wavelength of light source, the angle through which the film was rotated and the fringe count.
- Substitute these values in the formula to get the thickness of the thin film.

I. Formulae Used

$$frequency = \frac{2tk(\mu-1)\ sec(\varphi)\ tan(\varphi)}{\lambda}$$

$$w = \frac{2(n-1)\lambda}{4(\mu-1)} \quad [4]$$

$$w = t(sec\ -1) [4]$$

Equating the above two equations, we get

$$t = \frac{2(n-1)\lambda}{4(\mu-1)(sec\varphi - 1)}$$

Where,

t- thickness of the plate.
w- change in width from è = 0º to è =ö
k- constant in degrees/sec
ì - refractive index thin film
ö- angle through which the glass plate is rotated
ë- wavelength of light
n - fringe count

J. Results obtained

A thin transparent film of thickness 1mm and refractive index 1.5 was taken as a test sample.When the film was rotated through 20 degrees the counter showed a count of 99.

Substituting this in the formula

$$t = \frac{(2 X 99 - 1) X 650 X 10^{-9}}{(1.5-1) X 4 X 0.0642}$$

$$t = \frac{0.000064025}{0.0642}$$

= 9.9727413 x   meters
= 0.99727413 mm (very close to the actual value of 1mm)

TABLE I

Angle (in degrees)	Number of Fringes	Obtained Width (mm)
10	24	0.99059662
20	99	0.99727413

NOTE: As the angle through which the glass plate is rotated is increased the fringe count increases. This reduces the weight associated to each fringe count and thus the results get closer to the actual value there by making the instrument more accurate.

III. Conclusions

Thus a device for determining the thickness of a thin transparent film was designed and constructed and its working was tested using a sample glass plate. The challenges we faced were the disturbance induced by the ambient light and fluctuations due to vibrations. More over due to lack of buffer space at the line of reference counter errors are induced due to multiple reference crossing. Nevertheless the device was able to provide good results when certain precautions were under taken. There are some improvements which can be made to overcome these problems. These are stated below.

A. Enclosing the LDR in a black box with a pin hole to prevent hindrance from ambient lights.
B. Using Schmitt Triggers to convert the sine waves into pulses. This will bring in a buffer space near the reference and will reduce the counting errors induced by multiple reference crossing.
C. Increasing the counting range of the circuit. Presently it can count from 0 to 99. Increasing it by

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one or more digit will help in acquiringmore accurate reading.

D. The rotation of the film can be motorised. The speed of which can be controlled using a microcontroller programmed for pulse width modulation (in case of DC motors which are cheaper and smoother than the stepper motors.

IV.ACKNOWLEDGMENT

V. REFERENCES

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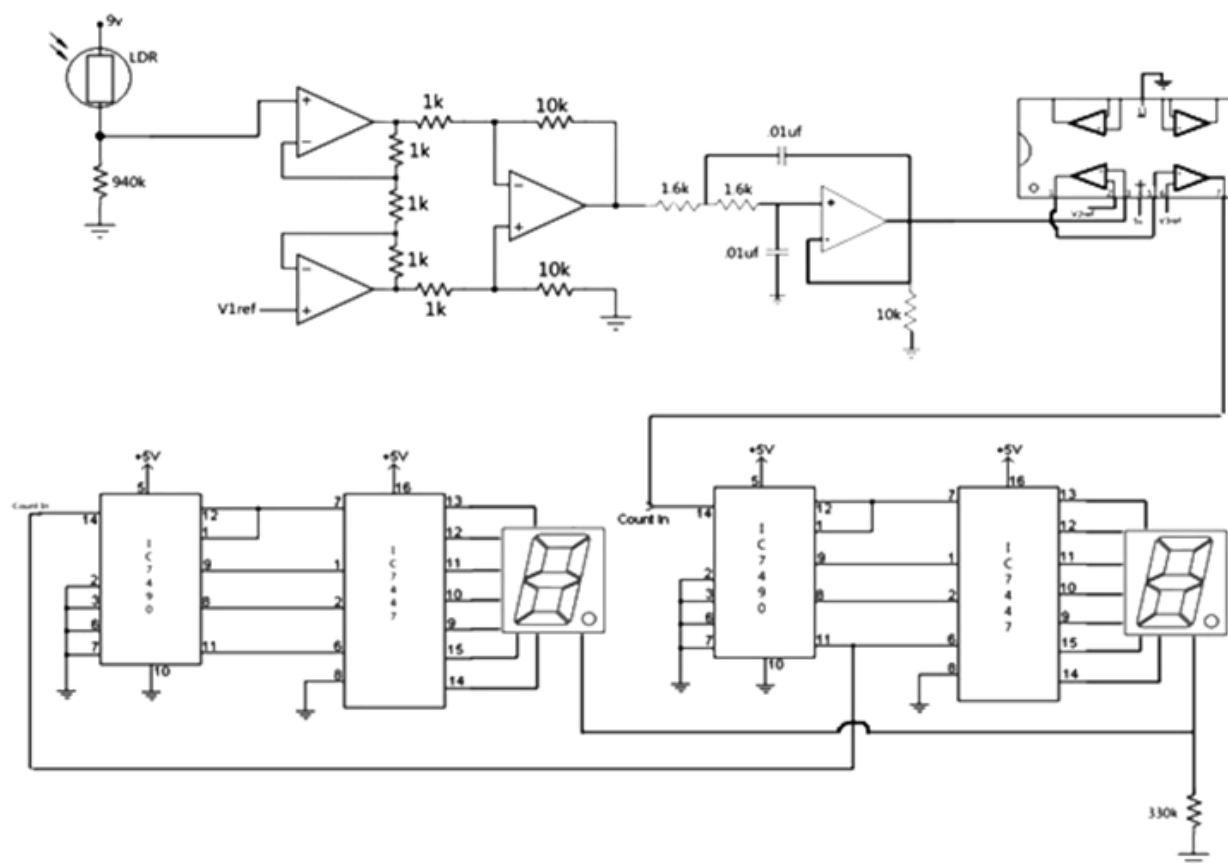[5] Sergio Franco, 'Design with operational amplifiers and analog integrated circuits', McGraw-Hill, 1997.

Figure 8 : The complete Circuit Diagram